How do you eat an elephant? How problem solving informs computational instruction in high school physics

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Science educators agree that computation is a growing necessity for curricula at many levels. One program looking to bring computation into high school classes is an NSF-funded program at Michigan State University called Integrating Computation in Science Across Michigan (ICSAM). ICSAM is a year-round program that brings a community of teachers together to help them equitably add computation into their physics curricula. While in the ICSAM program, data is collected from participating teachers through interviews, surveys, classroom videos, and more. In this paper, we examine a case study of an active participant who fits the mold of a typical high school physics teacher in the United States. We utilize the lenses of critical pedagogical discourses and contextual discourses to explore the decision-making behind the adoption of various resources by this teacher during their time with ICSAM. The ways in which this teacher integrated computation in their classroom, along with the nuanced challenges that they faced, might be able to help inform other teachers, professional development providers, and curriculum development of the nature of implementing computation into high school curricula. This work was supported by the National Science Foundation (DRL-1741575) and Michigan State University's Lappan-Philips Foundation.

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I. INTRODUCTION

Computational literacy is a growing need for students of science [1] – leading to a demand for computation in high school courses. This movement has left teachers with gaps in their education. Few are likely to have had experience with computation before teaching [2]. Professional development (PD) programs can help fill these gaps. Over the course of the last several years, Integrating Computation into Science Across Michigan (ICSAM) is one such program.

ICSAM is a PD program modeled after the Partnership for Integrating Computation into Undergraduate Physics (PICUP). ICSAM consists of a week-long summer program, workdays every two months during the school year, and informal communication in between. Like PICUP, it has a focus on building a community of teachers to help each other while integrating computation into their curricula [3].

The ICSAM program also utilized elements from P-Cubed, a set of introductory undergraduate physics courses at Michigan State University. P-Cubed's use of minimally working programs, utilization of computation as a vehicle for physics learning, and focus on groupwork and equity in the classroom all transferred over to ICSAM [4]. The program emphasized issues of equity in the classroom using the Equity Quantified in Participation (EQUiP) analytics. EQUiP analytics is a tool that allows practitioners to review classroom conduct in terms of discourse dimensions (e.g. level of participation, computer use) through the lenses of social markers (e.g. race, gender) EQUiP analytics have teachers utilize a priori coding to review recorded videos of classroom interactions to determine patterns of equity in their classrooms [5]. These patterns can identify inequities in classroom activities that may otherwise be overlooked.

In this study, we utilize the framework of critical pedagogical discourses (critical discourses) in terms of the way an individual conceptualizes teaching and learning [6]. We then apply these critical discourses as a lens to help us understand the decisions made by ICSAM teachers in their adoption of new resources to help them implement computation into their curricula. These critical discourses interact with the ICSAM program's contextual discourse to help the teachers form their own critical discourses around computational learning.

In this paper, we focus on one teacher participant, Hugh. Hugh's demographics, education, and coding experience, along with the amount of data he allowed us to collect made him a prime subject for a case study to examine how he integrated computation into his classroom, the tools and resources that he utilized while doing so, and how his critical discourse informed his choices.

Our central research question for this case is: What is Hugh's critical discourse and how does it inform his use of resources to design computational learning opportunities for his physics students?

II. THEORETICAL FRAMEWORK

Based on the qualitative technique critical discourse analysis (CDA), Thompson et al. utilized the idea of critical discourse to examine the development of novice teachers' ideas (or discourses) about the practice of teaching [6]. They referred to these discourses as critical pedagogical discourses, or, more compactly, critical discourses.

Analyzing a teachers' critical discourse requires examining the language they utilize surrounding their students and their classroom activities. We can then compile the teachers' stated and implied conceptualization of teaching and learning. The way teachers conceptualize teaching and learning is the core of their critical discourse.

Critical discourses are developed by teachers' experiences in various contexts, such as university teaching programs, or the school district where they teach. Each context has its own discourse, or its best practices and ideas of what teaching means within that context. When teachers are in a context for a significant amount of time, their own critical discourse can change.

The contextual discourse for ICSAM was made clear to the participating teachers through activities and the facilitators. This study is headed by some of those ICSAM facilitators. As facilitators, we believe it is important to provide participating teachers learning opportunities to understand ICSAM's contextual discourse and to potentially take up some of that discourse into their own. This discourse emphasizes the importance of computation for scientific learning, equity in educational spaces (through EQUIP,) and building a community of peers to share ideas with. As facilitators, we see ourselves as a part of that community of peers, sharing our own experiences in science education with our participants.

Each teacher participating in ICSAM has their own critical discourse, and ICSAM has its own contextual discourse. The teachers' critical discourses could be changed by participating in the ICSAM PD. However, the way they utilize the resources around them to achieve the goals set forth by the ICSAM PD (to add computation into their classrooms) will vary based on their critical discourses.

Thus, in this analysis, we utilize Hugh's critical discourse as a lens to understand how and why he used different resources, and how his critical discourse and resource use informed his instructional design.

III. DATA AND METHODS

A. Data collection

We collected various data over the course of the project. This included teacher surveys, demographic information on teachers' schools, and other information to give a complete picture of participating teachers' classroom environments, backgrounds, and level of comfort with coding.

In addition, ICSAM facilitators conducted two types of interviews with participating teachers. First, during the school year, debrief interviews (debriefs) were conducted after the workdays. These debriefs were informal, semi-structured interviews that utilized online EQUiP analytics to guide teachers through examining the patterns of equity in their classrooms. Each teacher participated in multiple debriefs depending on which workdays they attended.

Next, the resources interview was conducted near the end of the school year in 2020. This interview was also semi-structured, and more formal than the debriefs. Each teacher participated in one such interview. These interviews focused on the resources that the teachers used (or not) during their time with ICSAM and how the use changed over time.

In the case of Hugh, he participated in every workday for the two years prior to the COVID-19 pandemic. This provided a wealth of data from his debriefs. For this case study, we also completed an additional interview with Hugh. This interview was semi-structed, and the interview protocol was designed to fill in gaps from the other data sources.

With all this data, we were able to put together a good picture of Hugh's background, his classroom practices, and his ideas about teaching.

B. Case background

Hugh is a typical high school physics teacher in Michigan. Like many physics teachers, he has earned a STEM degree, but it's not in physics [7]. Both Hugh's bachelor's and master's degrees are in geology. The number of high school physics teachers with a degree in physics or physics education has been decreasing for the past twenty years [7]. Hugh is a career teacher; before he participated in ICSAM, he had taught physics for 14 years. Career teachers in physics, as defined by the American Institute of Physics' Statistical Research Center, are teachers who have taught high school for at least five years and have taught physics for at least half of their time teaching. This career trajectory is the most common for high school physics teachers [7].

Like most high school physics teachers, Hugh is white and a man [8, 9]. Hugh's students are relatively diverse, and the typical high school physics classroom has gotten increasingly diverse recently [10]. This puts teachers in an interesting spot, as they are increasingly likely to be teaching students who have had different life experiences from them.

Finally, most high school physics teachers are of the age where they likely would not have obtained computational experience in their undergraduate careers, whether they were in physics or not. In 2009, most high school physics teachers were over 30 years old [11]. The average and median age for teachers in the US is over 40 years old [12]. It was only in 2011 that the American Association of Physics Teachers AAPT) formally recommended that undergraduate physics degrees include some amount of computational work [13]. Hugh did not have any coding experience at his undergraduate level. The most coding he had before ICSAM was some experience with Fortran for research purposes. Hugh did not have experience with Python, the primary language used in ICSAM, prior to the PD.

IV. ANALYSIS

We utilized a combination of a priori and emergent coding of the resources interviews to develop a list of resources that the teachers discussed. The a priori codes were three different categories of resources utilized by researchers in mathematics education: *material* resources, features of settings that can be manipulated, such as time or physical resources; *social* resources emerging from interactions with other people, such as student emotional reactions or colleague interactions; and *intellectual* resources, teachers' evolving thinking or understanding of subject matter and pedagogy, such as previous coding experience [14,15].

The resources developed through emergent coding ultimately fit into one of the three a priori categories in our codebook. After our codebook was created from the resources interviews, we coded the debriefs, adding in additional emergent codes as we deemed necessary.

To help understand the motivations behind the adoption of different resources, we utilized the lenses of critical and contextual discourses while analyzing the data. We did not directly code for teachers' critical discourses. Instead, we made connections between the language the teachers used when discussing their teaching and learning and the subjects that they discussed. It is difficult to get a perfect sense of a teachers' critical discourse but we were able to get at least general ideas for each teacher.

These critical discourses then allowed us to better see why teachers utilized their resources in different ways, such as why one teacher never utilized a resource that another may have used abundantly.

Once all of Hugh's debrief interviews were coded, the code counts were normalized across each interview. The percent of the total codes that each code accounted for within the interview was compared over time to see how the content of the debriefs changed over time. Eight of the most prevalent codes and the percent of the discussion that they used can be seen in Fig. 1.

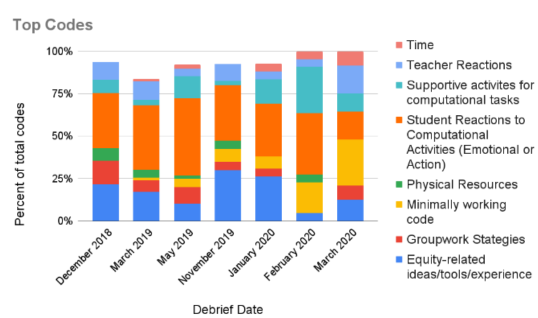

FIG. 1. A plot of the normalized code counts across time for eight of the top codes within Hugh's debrief interviews.

V. RESULTS AND DISCUSSION

Throughout analysis, we found two integral components of Hugh's critical discourse: student reactions and problem-solving. Taken together, they motivate many of the classroom practices that we found Hugh discussing in his interviews, which includes reasons why Hugh used or didn't use various resources.

A. Student Reactions

Hugh's critical discourse appears to center on the way students react to classroom activities. Student reactions was the most discussed resource over all the debriefs, for all but one of the debriefs, and for the resources interview (Fig. 1). It is clear not only from the coding of the interviews but also from the content of the interviews that Hugh views his students' reactions as a useful gauge for how his students are doing with the material. The in-class videos that we recorded and used for EQUiP analytics helped Hugh utilize this resource. Hugh values the feedback that students give via their emotional and physical reactions to activities.

In the resources interview, Hugh even states that he wants to help more students have a sense of accomplishment with their coding activities. He states that he believes that if he structures the coding activities in a way that ensures students complete the activity and get that sense of accomplishment, that will improve class engagement:

> *It was one where a majority of students were able to finish the activity within the hour. I think that was a huge kick for them. They were really geeked. Again, it came from watching the videos of them. They were really geeked to be able to finish something up in one class hour. ... So, it made me think that, "Well, maybe I need to structure things so more students have that experience." I think that might be more engaging. They learn something really tough. They're able to get it accomplished and walk out feeling, "Hey, I got something done."*

The EQUiP videos also helped Hugh to understand how difficult his coding was for his students. His critical discourse seems to have a lot of meaning attached to the difficulty of lessons. In the resources interview, he defines computational success as *"the level of struggle [being] appropriate."* He seems to believe that students need to be challenged but not so much that they give up, just challenged so that they have that "Aha!" moment. He states that this can be challenging with computational activities, but that it is important to find a middle ground.

This part of Hugh's critical discourse does not seem to have been changed much by the ICSAM PD. Rather, the videos of classroom observations that we provided him allowed Hugh to explore the way he would like his students to react to doing computational activities and to compare that to how they were reacting to these activities.

B. Problem-solving

The most salient aspect of Hugh's critical discourse was the idea that problem-solving can solidify ideas the students are trying to learn. Although it was not one of our resource codes, Hugh discusses problem solving in most of his interviews. In fact, Hugh included "Problem Solving Skills" as one of the dimensions that he looked for in his classroom videos. Hugh highly values problem solving and considers it central to physics learning. In the debriefs and the resources interview, he regularly discusses how he would like his students to break down a problem into smaller pieces:

> *This comes with pretty much anything where students are struggling. They have difficulty breaking down the problem into smaller components and solving those smaller components one at a time. Then putting those pieces together. It's the "How do you eat an elephant" problem. (chuckles) One bite at a time.*

For Hugh, his desire to get his students engaged in bit-by-bit problem solving motivated his utilization of various resources and in his level of acceptance of parts of ICSAM's contextual discourse.

1. Interaction with student reactions

The value that Hugh places on problem solving can be seen in his discussion of student reactions. He places value on a bit of struggle, that part of working through a problem, and then on the feeling of success that comes from finally solving a problem. Hugh watched to see *how* students were struggling with the problems. He wanted to see the students break the problem down into parts, and figure out each small part on their own, then bring them all together to see the big picture. Hugh was dissatisfied if he saw his students trying to take on too much of a problem at once.

2. Utilization of minimally working programs

Minimally working programs (MWP) are an essential part of ICSAM and P-Cubed [4]. MWP are programs that run but do not function properly. In the context of ICSAM, this is typically a program in Python that will run but will have incorrect or incomplete physics that the students are meant to change into a simulation of real-life physics. Students with no programming experience can apply or obtain physics knowledge while gaining experience reading and working with code.

For Hugh, his use of MWP aligned with the importance of problem solving and student reactions within his critical discourse. Hugh was able to utilize the student reactions that he saw in the recordings of his class to adjust his MWP to get his students to the level of problem-solving that he wanted. For example, Hugh mentioned leaving in more code than he previously had, so that the students had less to do to make it function and struggled less. In his interview, he states, *"I've overestimated the tenacity and capability of my students… That really came up in watching the videos."*

For Hugh, MWPs posed a challenge because he had little to no experience with Python before ICSAM. In the update interview, we asked Hugh about this. He discussed how his own coding ability influenced his ability to work with the MWP. He said once he was able to start reading and understanding error messages and learning which parts of the program were helpful to students, he was able to fine tune programming activities to the wide variety of programming experience his students had, and to ensure that the students took home the meaning of code. That is, that coding is just like other problem solving in that it can be broken into smaller problems and obstacles can be worked around, and that there are many practical applications to coding.

3. Physics before computation approach

In line with his focus on problem-solving, Hugh implemented computation in his classroom utilizing a "physics before computation" approach. This approach utilized computation to affirm students' knowledge in physics. This stands in contrast to the contextual discourse that the ICSAM PD tried to promote, which utilizes computation as a vehicle to introduce physics topics and help students to begin their understanding of physics topics.

Hugh sees problem-solving as breaking down a problem into smaller pieces and focusing on one at a time. When it came to computation in his classroom, he discussed that the students had an easier time digesting computation when they had learned the physics prior to the computational task.

This approach also makes sense given Hugh's experiences with computation. Due to the timing of his education, Hugh likely did not encounter computation in any physics or other STEM courses he might have taken in school. Computation is something Hugh learned separately from physics. He does not necessarily view computation as a vehicle for physics learning, but rather as something else that he needs to teach his class in addition to physics.

Due to the strength of Hugh's discourse surrounding problem solving, it is not surprising that the part of ICSAM's contextual discourse surrounding computation as a vehicle for physics did not have much of an effect on Hugh's teaching practices.

C. Equity

We can certainly see elements of Hugh's critical discourse in the design of computational opportunities. However, this discourse did not seem to include a strong focus on equity in the ways that our contextual discourse communicated. When Hugh discussed equity, it was often regarding inequities that were not from his classroom interactions. For example, Hugh discussed peer pressure contributing to lower female enrollment in the honors physics course when the name was changed from "Honors Physics" to "AP Physics 1."

Discussion of inequities within his classroom frequently led to ascribing that inequity to personality traits or temporary features that did not have to do with race or gender, such as level of familiarity with other group members. However, Hugh seemed to be aware of this. During one debrief, he mentioned that it would be helpful for him to have an outside eye look in on the EQUiP analytics and videos of his class to see trends of inequities and their potential causes. In this debrief from March 2019, he says:

> *Are there some things that an external reviewer could look at in the data? And then without knowing the students, be able to say, "Oh, there's this kind of trend here. This is something I noticed." That might be some helpful feedback for the individual teacher to think about when they go back to their classroom.*

While ICSAM facilitators were acting as interviewers during the debriefs, the facilitators did not tend to act as this outside reviewer, but rather as guides that helped the teachers talk through the analytics and what the teachers believed were the sources of inequities.

IV. CONCLUSIONS

Hugh's journey as he implements computation is an important one. We can see that as a physics teacher navigates the implementation of computation in their classes they must contend with a variety of decisions. Through Hugh, we find that these decisions can be informed by Hugh's own critical discourse – how he views the purpose and use of computation in his classroom. Hugh's critical discourse interacts with the learning Hugh has done in the professional development environment – an environment that has its own contextual discourse – how we view the purpose of use of computation in Hugh's classroom. As we continue to support teachers in implementing computation into physics classrooms, it behooves us to make salient teachers' critical discourses. Through that work, we can navigate the complexities of computational integration and better support students learning.

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